AMENDMENTS TO THE SPECIFICATION

On page 1, please replace the subheading "BACKGROUND OF THE INVENTION" with "BACKGROUND".

On page 3, please replace the subheading "SUMMARY OF THE INVENTION" with "SUMMARY".

On page 10, please replace the subheading "DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS" with "DETAILED DESCRIPTION OF THE VARIOUS EMBODIMENTS".

Please replace Paragraphs [0001], [0009-0013], [0022], [0024-0027], [0029-0031], [0034-0035], [0037], [0047], [0071], [0073], [0099], [0103-0113], with the following paragraph rewritten in amendment format:

[0001] The present ~~invention~~ disclosure is directed to image registration, and more particularly to a system and method for automatically registering images of different perspectives and images from sensors with different internal geometry.

[0009] The match process of the present ~~invention~~ disclosure solves the problem of registering images of different perspectives and images from sensors with different internal geometry.

[0010] Generally, the present ~~invention~~disclosure addresses the problem of relating sensor images to ground coordinate systems with high accuracy. This is accomplished by registering or aligning the sensor image with a precision geocoded reference image.

Because of this high precision, the geocoding of the reference image can be transferred to the sensor image with accuracy comparable to that of the reference image. The geocoded reference image, such as a DPPDB image provided by the National Imagery and Mapping Agency, provides a known accuracy in relation to ground coordinates. The present ~~invention~~disclosure also solves the problem of accurately registering a small sensor image to a much larger reference image, which may be taken as a stereo pair of images for some embodiments of this ~~invention~~disclosure where the two images have significantly different perspectives of the scene.

[0011] One aspect of this ~~invention~~disclosure makes use of knowledge of the approximate location of the scene as it is found in the reference image to limit the search area in attempting to match the small image to the larger image. Another aspect of the disclosure is the use of approximate knowledge of the sensor location and orientation, or the sensor model, at the time when the scene is imaged, as that knowledge, combined with knowledge of the scene location, may be used to reduce the search process. Yet another novel aspect is the use of the geometry of the scene area, as known or derivable for the reference image around the scene area, or as known or derivable for the sensor image, to modify one or both of the images to have a common geometry; that is, to eliminate perspective differences that arise from the two different views of the scene as imaged separately by the sensor and the reference.

[0012] Further in accordance with the ~~invention~~disclosure, knowledge of the sensor location and orientation and of the location of the scene is used to extract a small portion or "chip" of the reference image or images that encompasses the scene area imaged by the sensor.

[0013] Parameters of the sensor, such as field of view and resolution, together with measurements of range and directions in three dimensions to the scene depicted in the sensor image, determine a nominal "sensor footprint", or prospective location, orientation and size for the sensed scene and for the reference chip. However, these measurements are actually estimates that involve uncertainties, producing uncertainty in where the sensed area or footprint actually is and in its actual orientation and size. It can be noted that these same uncertainties also produce or involve the fundamental inaccuracies that this ~~invention~~disclosure is intended to overcome. The uncertainties are, however, known quantities, and are usually expressed in terms of error bounds on each measurement. This makes it possible to determine an uncertainty basket around the nominal sensor footprint, such that the scene's true location and its full extent will always fall within that uncertainty basket. The uncertainty basket defines the portion of the reference image to extract as the reference chip.

[0022] Of particular importance is the ability obtained using the ~~invention~~disclosure to identify the specific location in the reference image of a target point appearing in the sensor image, when said target may not even be depicted in the reference image, such as when the reference image was recorded at a time before the target was at that location in the scene area. By means of the spatial coordinates associated with each pixel in the reference image, the spatial scene coordinates of the unreferenced target may be discovered. In addition, by showing the corresponding location of the target point as mapped to the reference image, an observer examining the sensor image and its selected target point, and the reference image and its corresponding mapped target

point, can perform a judgment of the validity of the registration result, and of the target point placement in the reference image.

[0024] Further features and advantages of the present ~~invention~~disclosure, as well as the structure and operation of various embodiments of the present ~~invention~~disclosure, are described in detail below with reference to the accompanying drawings.

[0025] FIG. 1 is a block diagram of ~~a preferred~~ an embodiment of the processing architecture of the ~~invention~~disclosure for automatic image registration.

[0026] FIG. 2 is a diagram illustrating a sensor footprint derivation in accordance with a ~~preferred~~ embodiment of the ~~invention~~disclosure.

[0027] FIG. 3 is a diagram illustrating a bounding box for a sensor footprint in accordance with a ~~preferred~~ embodiment of the ~~invention~~disclosure.

[0029] FIG. 5 illustrates an example of an image registration process in accordance with a ~~preferred~~ embodiment of the ~~invention~~disclosure.

[0030] Generally, in accordance with the present ~~invention~~disclosure, a small sensor image is matched to a larger reference image. The large reference image typically covers a relatively large area of the earth at a resolution of approximately the same, or better than, that normally expected to be seen in the sensor image. The reference area may be any area that can be the subject of a controlled imaging process that produces an image with known geometric characteristics and know geometric relationships between locations in the image and locations in the subject area. For example, the reference area may be a portion of a space assembly or an area on the human body.

This reference typically involves hundreds of thousands, or even millions or more of pixels (picture elements) in each of its two dimensions, and may comprise a pair of such images in a stereoscopic configuration that admits stereography in viewing and measurement. The reference image is geocoded so that a geographic location can be accurately associated with each pixel in the image, including an elevation if a stereo pair of images is used. For other types of reference areas, locations other than geographic are used as suited to the application, but some reference coordinate system is the basis for the location measurements.

[0031] The sensor image, on the other hand, is fairly small, typically involving a few hundred or thousand pixels in each of its two dimensions. Resolution of the sensor image usually depends on the position of the sensor relative to the scene being imaged, but the relative positions of sensor and scene are normally restricted to provide some minimal desired resolution sufficient to observe appropriate detail in the scene and comparable to the detail shown in the reference image or stereo image pair. The sensor image typically depicts a different perspective from that of the reference image, often at a much lower, oblique, angle to the scene, whereas the reference image is typically from high overhead angles. On the other hand, the perspectives may be similar, such as for a synthetic aperture radar sensor, which typically presents a generally overhead view of the scene it images. These differences in geometry, whether arising from perspective differences or differences in sensor geometry, are a problem source addressed and solved by this ~~invention~~disclosure.

[0034] Numerous techniques of photogrammetry have been developed to identify acquisition parameters of sensors that produce characteristic perspective and scale properties in images. This ~~invention~~disclosure makes use of such knowledge as is available about the images to reduce the matching problem to a tractable size so that a best match can be obtained along with a quality measure of the match to indicate its validity/invalidity.

[0035] In accordance with a ~~preferred~~ embodiment of the ~~invention~~disclosure, first the size of the reference image area to be searched is limited. With knowledge of the location of the sensor, its imaging properties (such as field of view and scale), and the location of the scene being sensed (such as the scene center), it is possible to determine the area within the reference image imaged by the sensor. This footprint of sensed image is extended by adding to it uncertainties in the locations of the sensor and scene. These uncertainties may include uncertainty as to look angles to the scene, range to the scene center, field of view, and pixel resolution in the scene. It is preferred to ensure that all uncertainties that influence the location of the sensed area within the reference image be taken into account. If the obliquity of the sensed image is low, so that a shallow view of the scene area is obtained by the sensor, it is possible that the area sensed will be quite large in the reference image. In this case, the scene area identified preferably is reduced to include amounts of area in front of and behind the scene center, as seen by the sensor, equal to a distance in front or behind the scene area of no more than twice the width of the sensed area, as seen by the sensor.

[0037] The chip is then distorted or warped to conform to the known geometry of the sensor image. In accordance with the ~~invention~~disclosure, this involves several operations which may be performed in a variety of different sequences, or as a variety of combined operations, all of which result in a similar warping. One such sequence of operations will be described, but it is to be understood that other such operations know to those skilled in the art of image processing fall within the scope of this ~~invention~~disclosure.

[0047] A ~~preferred~~ embodiment of the ~~invention~~disclosure will further be described with reference to the drawings. Particularly with reference to FIG. 1, there is shown a block diagram of a processing architecture 10 for automatic image registration in accordance with a ~~preferred~~ embodiment of the ~~invention~~disclosure. Generally, the process comprises the following operations:

[0071] 4b. If the reference image 28 consists of a left and right stereo pair, a chip is extracted from each to cover the AOI. The associated stereo model is then exploited to derive a DEM over the AOI. This DEM is accurately associated or aligned with each of the left and right chips, just as a reference DEM is associated or aligned with the reference image 28. Such stereo DEM extraction is performed using standard techniques in any number of commercially available software packages and well documented in the literature. It is the utilization of such techniques for automatic, unaided stereo extraction that is unique to the present ~~invention~~disclosure.

[0073] 5a. If the reference chip 30 is not an orthographic image, or is not close to orthographic, so that it exhibits perspective distortion (say more than ten degrees off from a perpendicular view of the scene area so that there is perspective distortion to be seen), it is desirable to remove the perspective distortion by producing the orthographic reference chip 48. This is accomplished using the reference chip 30 together with the reference DEM chip 42, as well as information about the reference image perspective. Such information is normally expressed in the form of mathematical mappings that transform coordinates of the reference scene area (such as geographic coordinates when the scene is of the ground and a height coordinate from the corresponding DEM) into coordinates of the digital or film image. The stereo extraction method of constructing a DEM also yields such information. Construction of the orthographic reference image chip 48 uses standard commercially available techniques. It is the utilization of such techniques to automatically produce orthographic images in an unaided fashion that is unique to the present ~~invention~~disclosure.

[0099] 8. Image match 60 is then carried out, between the synthetic perspective reference chip 58 and the sensor image 12. Again, there are many techniques that can be used, from a simple normalized image correlation, such as may be performed in the Fourier image transform domain, to a more robust, cross-spectral method like the Boeing General Pattern Match mutual information algorithm described in U.S. Pat. Nos. 5,809,171; 5,890,808; 5,982,930; or 5,982,945 to another more robust, cross-spectral method like a mutual information algorithm described in P. Viola and W. Wells, "Alignment by Maximization of Mutual Information" International Conference on

Computer Vision, Boston, Mass., 1995. It is unique to the present ~~invention~~disclosure that the only remaining difference between the two images after the processing described above, is a translation offset. This makes the match problem much easier to solve, requiring less computation and yielding a more accurate match result.

[0103] FIG. 5 illustrates an example of an image registration process 100 of the present ~~invention~~disclosure.

[0113] While the present ~~invention~~disclosure has been described by reference to specific embodiments and specific uses, it should be understood that other configurations and arrangements could be constructed, and different uses could be made, without departing from the scope of the ~~invention~~disclosure as set forth in the following claims.